MASTER OF SCIENCE
IN
APPLIED PHYSICS

SUPERSONIC FLOW PAST TWO OSCILLATING AIRFOILS
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Master of Science in Applied Physics-June 1998
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Supersonic flow past two oscillating airfoils with supersonic leading edge locus is analyzed using an elementary analytical theory valid for low frequencies of oscillation. The airfoils may have arbitrary stagger angle. This approach generalizes Sauer's solution for a single airfoil oscillating at small frequencies in an unbounded supersonic flow.

It is shown that this generalization can provide an elementary theory for supersonic flow past two slowly oscillating airfoils. This aerodynamic tool will facilitate the evaluation of pressure distributions and consequently the calculation of moment coefficient. Torsional flutter boundaries are computed. The results for the pitch-damping coefficient are the same when compared with previous analysis. For arbitrary frequencies a linearized method of characteristics was outlined.

The elementary theory that has been developed in the thesis can be used for flutter evaluation of aircraft carrying external stores. The result of the thesis is the derivation of the pitch-damping coefficient which is necessary to predict the flutter conditions.

DoD TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Flutter Analysis, Structures

INVESTIGATION OF A SHIPBOARD WATER SCREEN FOR INFRARED GUIDED CRUISE MISSILE DEFENSE
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The most serious threat any modern ship faces on the modem battlefield is the proliferation of anti-ship missiles. As technology advances, it is certain that these missiles will only become smarter and more lethal. Many of these missiles will employ infrared (IR) seekers (stand alone or in conjunction with radar) to improve target classification and recognition, as well as to defeat conventional RE seeker countermeasures.

This research investigates the use of IR signature suppression from a water screen to delay detection, cause the missile to break lock, or seduce the selected aimpoint away from the most vulnerable areas. A series of proof of concept experiments were conducted to investigate several water screen types. The U.S. Army NVEOD program called FLIR92 was used to evaluate several imaging systems. The FLIR92 performance output and the water screen effect data, from the proof of concept experiments, were applied to a modified range detection probability program called ACQUIRE. Real world atmospheric data from the Gulf of Oman were applied to the model. The effect of a water screen over the entire ship, as well as over specific hot spots, was studied. The water screen suppressed the ship's IR signature. The degree of suppression was highly dependent on the quantity and quality of water screen involved.

The concept, proven in experiment and validated by computer models, was then applied to different tactical applications. The computer simulation shows a 1.2-meter mist screen reduced the detection range by 25% for a destroyer. Presenting a bow/stem aspect and a mist screen achieved a detection range that is 63% less than that of a normal beam aspect. Partial screening may also be use as an effective mean of IR seeker seduction. Furthermore, it may be possible to shift the seeker aim point to areas of less vulnerability.

DoD KEY TECHNOLOGY AREAS: Electronic Warfare, Sensors, Modeling and Simulation

KEYWORDS: Ship, Infrared, IR, Suppression, Masking, Defense, Stealth

SPIN AND MAGNETISM: TWO TRANSFER MATRIX FORMULATIONS OF A CLASSICAL HEISENBERG RING IN A MAGNETIC FIELD

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Nanometer scale fabrication and experimental investigations into the magnetic properties of mesoscopic molecular clusters have specifically addressed the need for theoretical models to ascertain thermodynamic properties. Technological applications germane to these inquiries potentially include minimum scale ferromagnetic data storage and quantum computing. The one-dimensional nearest neighbor Fleisenberg spin system accurately models the energy exchange of certain planar rings of magnetic ions. Seeking the partition function from which a host of thermodynamic quantities may be obtained, this thesis contrasts two transfer matrix formulations of a classical Heisenberg ring in a magnetic field. Following a discussion of the transfer matrix technique in an Ising model and a review of material magnetic characteristics, a Heisenberg Hamiltonian development establishes the salient integral eigenvalue equation. The 1975 technique of Blume *et al* turns the integral equation into a matrix eigenvalue equation using Gaussian numerical integration.This thesis alternatively proposes an exactly formulated matrix eigenvalue equation, deriving the matrix elements by expanding the eigenvectors in a basis of the spherical harmonics. Representing the energy coupling of the ring to a magnetic field with symmetric or asymmetric transfer operators develops pragmatically distinctive matrix elements; the asymmetric yielding a simpler expression. Complete evaluation will require follow-on numerical analysis.

DoD KEY TECHNOLOGY AREAS: Materials, Processes, and Structures; Modeling and Simulation

KEYWORDS: Nanomagnetism, Heisenberg Ring in a Magnetic Field, Magnetic Molecular Clusters, High Spin Molecule Thermodynamics, Partition Function Generation Via Approximate Versus Exact Matrix Eigenvalue Equation Formulations

OPTIMUM SYMMETRICAL NUMBER SYSTEM PHASE SAMPLED DIRECTION FINDING ANTENNA ARCHITECTURES

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A new interferometer direction finding array architecture based on the optimum symmetrical number system (OSNS) is presented. OSNS arrays are capable of unambiguous high-resolution direction finding with as few as three elements, with multiple baseline options. The OSNS DF antenna architecture being investigated uses the OSNS to decompose the analog spatial filtering operation into a number of parallel sub-operations (moduli) that are of smaller complexity. One two-element interferometer is used for each sub-operation and only requires a precision in accordance with its modulus. A much higher spatial resolution is achieved after the sub-operations are recombined. By incorporating the OSNS concept, the

dynamic range of a specific configuration of antenna element spacings and comparator arrangements can be analyzed exactly. In this thesis, the OSNS DF antenna concept was demonstrated experimentally, by designing, fabricating and measuring the performance of a three-element array at 8.5 GHz. These three elements are grouped into two pairs (channels) according to the set of relatively prime moduli ($in_1 = 6$, $in_2 = 11$). A mixer is used to determine the phase difference between each pair of elements. The output voltage from the mixer in each channel is a symmetrical folding waveform that is DC biased and amplified using a summing amplifier. The output voltage of the amplifier is amplitude analyzed using a small comparator ladder. An EEPROM is used to recombine the results of these low precision channels to yield the high resolution direction of arrival (DOA). Simulated and experimental results are presented and compared.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Direction Finding Antennas, Array Antennas, Rectangular Aperture Antennas, Open-ended Waveguides, Optimum Symmetrical Number System (OSNS), Weighted Summing Amplifier, Analog-to-Digital Converter, Comparator ladder.

REAL-TIME 3D SONAR MODELING AND VISUALIZATION

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Virtual world simulations are realistic when each individual component is simulated in a manner that reflects reality. For an underwater virtual world that simulates acoustic detection, a physically based sonar propagation model is required if ranges in excess of tens of meters are expected.

This thesis creates an application programming interface (API) for realtime 3D computation and visualization of acoustic energy propagation. The API provides features for generating complex physically based sonar information at interaction rates, and then visualizing that acoustic information. The simulation is programmed in Java and runs either as a stand-alone program or as a script in a web browser. This program generates Virtual Reality Modeling Language (VRML 97) compliant code that can be viewed from any VRML-capable browser. This approach allows the characteristics of the energy propagation to be calculated with high precision and observed in 3D.

As sonar system information bandwidth becomes larger, more intuitive ways of presenting information to a user will be required. Higher information density in a more intuitive format can free the user from integrating the data himself and allow quicker reaction times. This thesis and the API provide the foundation for fundamental advances in sonar modeling and visualization.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Modeling, Simulation, Sonar, Ray Tracing, Visualization, VRML

WIRELESS LOCAL AREA NETWORKS: SIMULATION AND ANALYSIS

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Wireless communication is currently in a state of rapid evolution. This evolution is driven by the numerous advantages of the wireless networks. One major constraint to this evolution is the lack of standardization. Also a major concern are the

interference problems of the signal at the reception point caused by the multiple paths that the electromagnetic waves travel (multi-path interference).

This thesis presents two separate simulations. In the first, a realistic physical model of a wireless local area network is developed. In this simulation, the multi-path interference at the reception point is investigated. The results of this physics-based simulation are used to assess an important assumption in the second simulation.

In the second part, we examine the reliability of the wireless standard for the medium access control (MAC) layer, using CACI COMNET III network simulation software. This standard was published in 1997, by the IEEE's working group 802.11 and in this thesis is tested and analyzed under different network loads. One major result is that the optimum load for a five working stations wireless LAN, is from 80 to 200 packets per second. Below that load range the channel utilization is small and above that the network is overloaded.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Multipath Interference, Irradiance, Wireless Local Area Networks, CSMA\CA Wireless I-AN Protocol, Channel Utilization, Packet Delay

SIMULATION OF PROPOSED 20 KW KLYSTRON FREE ELECTRON LASER

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The Free Electron Laser (FEL) is a potential solution for the U.S. Navy's anti-ship missile point defense by providing an evolutionary increase in weapon accuracy. To become an effective weapon, the FEL will need to provide an average optical power of approximately one MW. Towards this goal, the Thomas Jefferson National Accelerator Facility (TINAF) in Newport News, Virginia is constructing the first kW EEL, and desires to improve the design to 20 kW while maintaining less than 6% energy spread. Using a klystron undulator is one potential way to accomplish this. Given design parameters of a proposed free electron laser by TINAF, this study quantifies via simulation the behaviors of gain, power and energy spread as functions of desynchronism and a klystron's disperse strength. Specifically, it shows that a conventional undulator appears capable of meeting all TINAF design requirements.

DoD KEY TECHNOLOGY AREA: Directed Energy Weapons

KEYWORDS: Free Electron Laser, Undulator, Klystron

DIGITAL DATA ACQUISITION FOR LASER RADAR FOR VIBRATION ANALYSIS

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Laser radar for vibration analysis represents a military application to develop a target identification system in the future. The problem addressed is how to analyze the vibrations of a target illuminated by the laser radar to achieve a positive identification.

This thesis develops a computer-based data acquisition and analysis system for improving the laser radar capability. Specifically, a review is made of the CO_2 laser radar, coherent detection, and data acquisition software and signal processing.

These aspects form the basis for a laser radar system, using LabView software for data acquisition and signal analysis, which is capable of detecting vibrations from a stationary target. The laser radar was able to detect the frequencies of vibration of a test target. All the data can be recorded by the system. The laser radar presented could be used for further development and production of a target identification system.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: CO_2 Laser Radar Equations, Vibration Detection, Optics, Acousto-Optic Shift, Target Identification, Detectors, Data Acquisition

COMPARISON OF THE UNDERWATER AMBIENT NOISE MEASURED IN THREE LARGE EXHIBITS AT THE MONTEREY BAY AQUARIUM AND IN THE INNER MONTEREY BAY

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Ambient underwater acoustic noise recordings were made in three large exhibits at the Monterey Bay Aquarium and the inner Monterey Bay, with the results reported here. Observed broadband (0-6.4 kHz) acoustic noise levels ranged from 112-125 dB re 1 μP for the aquarium exhibits under normal operating conditions. Broadband acoustic noise levels of 113 dB and 116 dB re 1 μPa were observed for the nearshore and offshore bay locations, respectively.

A comparison of the noise spectrum in the aquarium's largest exhibit to that of the environment which it attempts to simulate, the offshore bay, revealed a higher noise level of approximately 15-25 dB in the exhibit for frequencies between 20 Hz and 6.4 kHz. A similar comparison of the noise spectra of the two smaller exhibits and the nearshore bay location revealed a difference of approximately 5-10 dB across the entire frequency range of 0-6.4 kHz.

Aquarium measurements with various mechanical equipment (motors, fans, pumps, sprinklers, wave machine) turned on and off highlighted some of the prominent ambient noise contributors. It was concluded that the pump machinery is the greatest contributor to ambient noise, with the strength directly related to the exhibits' proximity to the machinery room.

DoD KEY TECHNOLOGY AREA: Other (Underwater Acoustic Ambient Noise)

KEYWORDS: Ambient Noise, Noise Measurements, Aquarium, Monterey Bay

SIMULATIONS OF THE PROPOSED TJNAF 20 KW FREE ELECTRON LASER

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As the Navy's role as peace enforcer in support of ground troops draws Navy combatants into the littoral warfare environment, surface combatants will have to deal with decreased reaction times while engaging ever-faster anti-ship missile threats. The Phalanx Close-In Weapon System (CIWS) does not offer sufficient accuracy or engagement ranges to fight these threats, and conventional chemical lasers, which operate at fixed wavelengths, lack the tunability to operate in a dynamic ocean environment.

The Free Elctron Laser (FEL) offers the wavelengh tunability, fast reaction times, and the pinpoint accuracy necessary to ensure protection of Navy surface combatants into the future. In support of this goal, the Navy is funding a proposed 20 kW FEL at Thomas Jefferson National Accelerator Facility (TJNAF) in Newport News, VA. This FEL will feature a klystron undulator, designed to improve gain in weak optical fields, and a loop that will feed electrons back to the accelerator.

Simulations in this thesis vary the dispersive section strengths of the klystron undulator and desynchronism between the optical and electron pulses in order to find dispersive strength and desynchronism values that optimize the effects on final power and weak-field gain, while maintaining an electron energy spread less than TNJAF's goal of 6% to ensure proper feedback of electrons to the accelerator. Results show TNJF's 20 kW FEL design will reach a final power of 19.2 kW with an energy spread of 6% at desynchronism of $d = 0.03$ using a conventional undulator.

DoD KEY TECHNOLOGY AREA: Directed Energy Weapons

KEYWORDS: Free Electron Laser, Undulator, Klystron

A MATHEMATICAL MODEL OF KNEE KINEMATICS
UTILIZING THE PRINCIPLE OF MINIMUM ENERGY

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This thesis seeks to determine if the path of motion of the knee in passive flexion results from the minimization of potential energy in the joint ligaments. To investigate this hypothesis, a simulation modeling both collateral and cruciate ligaments was developed, with each cruciate ligament represented as two separate fibers. The model computed almost 8000 possible orientations of the femur during flexion through 120, with the surfaces of the femur and tibia serving as a constraint to motion. Each orientation of the femur inherently provided the position of the individual ligament attachment points, from which the extension or contraction and the potential energy of the ligament were derived. The energy of the entire six-ligament system resulted from the summation of the potential energy of individual ligaments. For each 10 of flexion, the femur position that produced the minimum energy of this six-ligament system was identified. Finally, the motion of the femur as it followed these positions was evaluated: it did not mirror known joint motion. There are several areas where further refinement of the simulation can be made before a complete evaluation of the hypothesis can be made.

DoD KEY TECHNOLOGY AREA: Biomedical

KEYWORDS: Energy Minimization, Knee, Flexion, Ligament